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# The Higgs Boson Might Not Couple To $B$ Quarks.

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## Abstract

We discuss an alternative version of the electroweak standard model, in which only the heavy  $t$  quark, not the light fermions, couples to the Higgs boson with a strength given by the standard model. The Higgs particle decays dominantly into two gluons jets. The branching ratio for the  $2\gamma$  decay is about 3.5 %. The Higgs particle would be a narrow object (width about 60 KeV), and its mass might be consistent with the value given by typical estimates of radiative effects measured by the LEP experiments.

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As far as the mass generation within the framework of the standard electroweak model is concerned, one must differentiate between the mass generation for the electroweak bosons  $W$ ,  $Z$ , the mass generation for the heavy  $t$  quark, and the generation of mass for the leptons and the five remaining, relatively light quarks. While there exists no freedom in the choice of the interaction strengths of the weak bosons with the scalar field, which is dictated by the gauge invariance [1], there is such a freedom with respect to the fermions. The masses of the fermions are given by the various Yukawa coupling constants, which parametrize the interactions of the leptons and quarks with the scalar field. The Yukawa coupling constant of the  $t$  quark field is of the same order as the gauge coupling constant, while the other fermions couple much weakly (0.018 for the  $b$  quark, 0.005 for the  $c$  quark, etc.). The origin of the light fermion masses is still mysterious, and alternative views or slight variations of the standard electroweak theory might indeed give a different view. Taking into account the observed flavor mixing phenomenon, one could speculate, for example, that the masses of the light quarks and of the leptons are due to the mixing. In the absence of the mixing the mass matrix of the quarks in the  $u$ -sector would simply be proportional to a diagonal matrix with the entries  $(0, 0, 1)$ , and there would only be a coupling of the scalar field to the  $t$  quark. Once the flavor mixing is switched on, the mass eigenstates for the light quarks are not necessarily coupled to the scalar field, with a strength given by the mass eigenvalues. In particular these couplings could remain zero.

It is well-known that the renormalizability of the theory requires a coupling of the fermion to the scalar field [1]. Otherwise the unitarity in the  $s$  channel is violated at high energies for the reaction  $f_L \bar{f}_L \rightarrow W^+ W^-$ .

However, for all fermions except the  $t$  quark these problems appear only at extremely high energies. Modifications of the electroweak theory, which involve an energy scale not orders of magnitude above the typical electroweak scale of about 0.3 TeV, e.g. theories which do not rely on the Higgs mechanism, can take care of this problem.

Recently we have discussed such a modification [2], or rather an alternative description of the standard model, based on the complementarity between confinement and Higgs phase [3]. We suppose that the electroweak interactions are described by the confinement phase, and not by the Higgs phase, as usually assumed. This provides an alternative view of the electroweak bosons, which are not the basic gauge bosons of the underlying gauge theory, but “bound states” of an underlying scalar field, which in the Higgs phase plays the role of the Higgs doublet. Both the charged  $W$  bosons and the neutral  $Z$  boson are  $J = 1$  bound systems of the type  $hh$ ,  $(hh)^\dagger$  or  $\bar{h}h$  respectively. There is a corresponding  $J = 0$ ,  $\bar{h}h$  system, which is to be

identified with Higgs boson of the standard electroweak model.

In a simple non-relativistic picture of these bound states the  $s$  wave state would in general have a mass less than the mass of the  $p$  wave state, e.g. the Higgs bosons would have a mass below 81 GeV. This need not be the case here, due to relativistic effects, and due to the complicated interplay between the confining gauge force and the scalar self-interaction, but nevertheless the mass of the Higgs boson is not expected to be very large compared to the  $W$  boson. The mass splitting between the Higgs boson and the  $W$  boson could be calculated using the lattice approximation, but since this has not yet been done, we are not able to make predictions for the Higgs mass.

We shall consider a deviation from our original model which would have the same couplings as in the standard model. It is conceivable that in the confinement phase of the electroweak theory the coupling strength of the fermions to the scalar boson are not proportional to the light fermion masses, since these couplings depend strongly on the dynamics of the model. In the simplest case only the fermion whose mass is of the same order as the weak interaction energy scale, i.e., the  $t$  quark, has such a coupling. Thus we proceed to calculate the properties of the scalar boson, which couples only to the  $t$  quark. As far as the interaction of such a boson with the  $W$  and  $Z$  bosons is concerned, there is no change in comparison to the standard electroweak model. However there is a substantial change of the decay properties. Decay modes which were regarded as being strongly suppressed become dominant.

We thus consider the following decay channels for the Higgs boson:  $H \rightarrow gg$  (see graph 1) via a top quark triangle and  $H \rightarrow \gamma\gamma$  (see graphs 2, 3 and 4) via a triangle involving top quarks and charged electroweak bosons or a bubble diagram involving a neutral electroweak boson. For a two photon Higgs decay, ignoring radiative corrections, one finds [4]

$$\Gamma(H \rightarrow \gamma\gamma) = \frac{\alpha^2 g^2}{1024\pi^3} \frac{M_H^3}{M_W^2} \left| \sum_i e_i^2 N_{ci} F_i \right|^2 = \frac{\alpha^2 g^2}{1024\pi^3} \frac{M_H^3}{M_W^2} \left| \frac{4}{3} F_{1/2} + F_W \right|^2 \quad (1)$$

where the functions  $F_{1/2}$  and  $F_W$  are given by

$$F_{1/2} = -2\tau[1 + (1 - \tau)f(\tau)] \quad (2)$$

and

$$F_W = 2 + 3\tau + 3\tau(2 - \tau)f(\tau) \quad (3)$$

where  $\tau = 4m_t^2/M_H^2$ . The first function corresponds to the contribution of the top quark and the second to the contribution of the charged  $W$  bosons.

channel	$m_H=60$	$m_H=70$	$m_H=80$	$m_H=90$	$m_H=100$
$\Gamma(H \rightarrow gg)_{\alpha_s=0.119}$	$2.3 \times 10^{-5}$	$3.7 \times 10^{-5}$	$5.5 \times 10^{-5}$	$7.9 \times 10^{-5}$	$1.1 \times 10^{-4}$
$\Gamma(H \rightarrow gg)_{\alpha_s=0.15}$	$3.6 \times 10^{-5}$	$5.8 \times 10^{-5}$	$8.7 \times 10^{-5}$	$1.3 \times 10^{-4}$	$1.7 \times 10^{-4}$
$\Gamma(H \rightarrow \gamma\gamma)$	$8.0 \times 10^{-7}$	$1.3 \times 10^{-6}$	$2.0 \times 10^{-6}$	$3.0 \times 10^{-6}$	$4.4 \times 10^{-6}$
$\Gamma(H \rightarrow WW)$	$1.09 \times 10^{-7}$	$3.80 \times 10^{-7}$	$1.22 \times 10^{-6}$	$4.49 \times 10^{-6}$	$2.66 \times 10^{-5}$
$\Gamma(H \rightarrow ZZ)$	$3.33 \times 10^{-8}$	$1.10 \times 10^{-7}$	$3.27 \times 10^{-7}$	$9.12 \times 10^{-7}$	$2.72 \times 10^{-6}$

Table 1: Higgs boson decay rates in GeV for different Higgs masses in GeV.

As we assume that the Higgs boson is light, i.e., lighter than twice the mass of the  $W$  bosons, the function  $f(\tau)$  reads

$$f(\tau) = \left( \arcsin \left( \sqrt{\frac{1}{\tau}} \right) \right)^2. \quad (4)$$

For the decay into two gluons one finds [4]

$$\Gamma(H \rightarrow gg) = \frac{\alpha_s^2 g^2}{512\pi^3} \frac{M_H^3}{M_W^2} |F_{1/2}|^2, \quad (5)$$

also neglecting the radiative corrections. The function  $F_{1/2}$  was given in equation (2).

Another possibility for the Higgs boson to decay are the electroweak boson channels  $H \rightarrow WW$  and  $H \rightarrow ZZ$ . The Higgs boson couples to the electroweak bosons with the same strength as in the standard model. The decay via two virtual electroweak bosons represents a non-negligible contribution to the Higgs decay. For  $m_W < m_H$  or  $m_Z < m_H$  one of the electroweak bosons is on-shell. These decay rates were evaluated using the program HDECAY [5] and cross-checked using CompHEP [6]. The numerical results are the sum of the decay over two electroweak bosons, for a light Higgs both electroweak bosons are virtual, when allowed by the kinematics, the contributions of on-shell electroweak bosons are also taken into account.

The results of these calculations are given in table 1. The corresponding branching ratios are given in table 2. We see that such a Higgs boson would decay in a fundamentally different way than the Higgs boson of the standard model. The results for the  $H \rightarrow gg$  decay are strongly dependent of the value chosen for  $\alpha_s$ . Thus this decay channel has a considerable uncertainty. We have done the calculations for two different values of the strong coupling constant  $\alpha_s = 0.119$  and  $\alpha_s = 0.15$ . The fine-structure constant was taken to be  $\alpha = 1/128.9$ .

Even if the light fermions in particular the  $b$  quark, do not couple directly to the Higgs boson, some  $b$  quarks could be produced via the diagrams 5 and

6. Their contributions is not easy to estimate but the electroweak corrections for a light Higgs are known to be very small [7], typically 0.3% of the tree level value. Nevertheless they could still be of the same order of magnitude as the  $\gamma\gamma$  contribution. Above 90 GeV the decay channel  $H \rightarrow Z\gamma$  opens. For masses larger than 110 GeV the Higgs boson mainly decays into two electroweak bosons.

The present searches for the Higgs boson at LEP are mainly based on the assumption that the leading decay made in the mass region of about 100 GeV or less is the decay  $H \rightarrow b\bar{b}$ . The present experimental limit  $m_H > 113.3$  GeV [8] is obtained on the basis of this assumption. In our model the decay is dominated by the decay  $H \rightarrow gg$ , i.e., the decay products do not show a specific flavor dependence. The lower limit on the mass of such a boson is much weaker and of the order of 70 GeV [9].

The best way to detect the Higgs boson at LEP seems to us to search for the decay  $H \rightarrow \gamma\gamma$ . Since the invariant mass of the  $2\gamma$  system would be identical to the mass of the boson, the background coming from radiation effects could be substantially reduced. In our case this decay channel, having a small branching ratio, is not seriously constrained by fermiophobic Higgs studies [8].

Typical fits of the Higgs boson mass indicate that the most likely mass of the boson is about  $77^{+69}_{-39}$  GeV [10]. It might well be, that the mass of the Higgs boson is in the region 70 to 110 GeV, provided the decay proceeds via the mechanism discussed above. We note that in contrast to the standard expectation the Higgs particle is a relatively narrow object with a width of about 58.5 KeV.

channel	$m_H=60$	$m_H=70$	$m_H=80$	$m_H=90$	$m_H=100$
$Br(H \rightarrow gg)$	96.06 %	95.39 %	93.94 %	90.39 %	76.54 %
$Br(H \rightarrow \gamma\gamma)$	3.34 %	3.35 %	3.42 %	3.43 %	3.06 %
$Br(H \rightarrow W W)$	0.46 %	0.98 %	2.08 %	5.14 %	18.51 %
$Br(H \rightarrow Z Z)$	0.14 %	0.28 %	0.56 %	1.04 %	1.89 %

Table 2: Branching ratios for different Higgs masses in GeV and for  $\alpha_s = 0.119$ .

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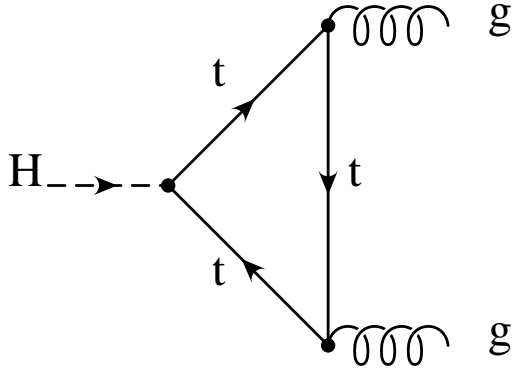


Figure 1: Top triangle.

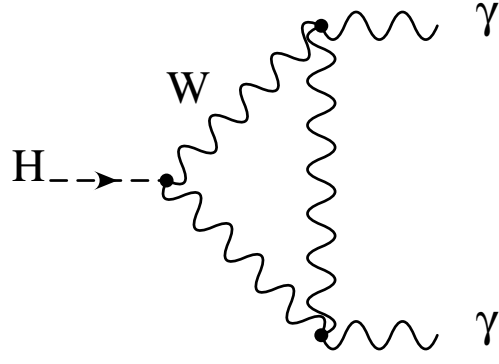


Figure 2:  $W$  triangle.

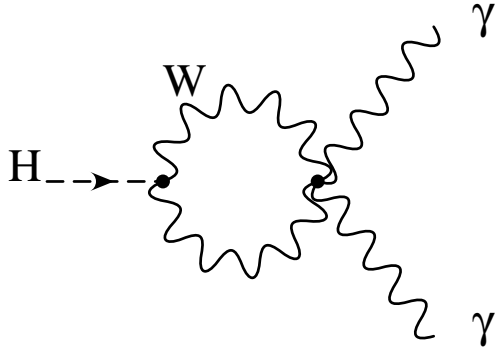


Figure 3:  $W$  bubble.

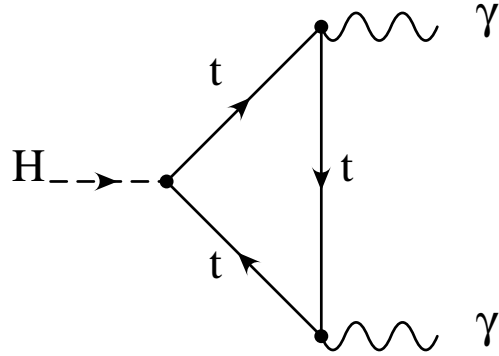


Figure 4: Top triangle.

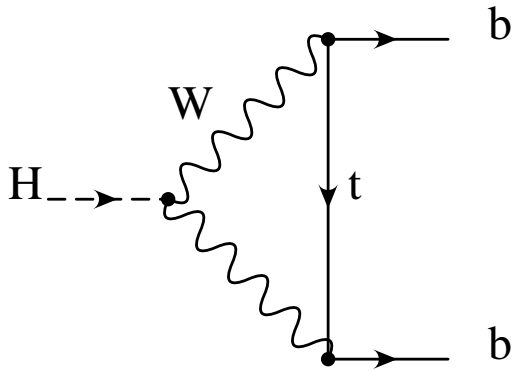


Figure 5: 1st effective  $b$  quark decay.

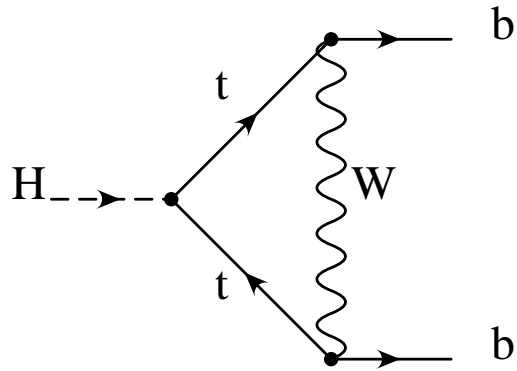


Figure 6: 2nd effective  $b$  quark decay.